(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 129 558 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
08.02.2023 Bulletin 2023/06

(21) Application number: **21795705.9**

(22) Date of filing: **22.03.2021**

(51) International Patent Classification (IPC):
B23K 26/32 *(2000.01)* ***B23K 26/21*** *(2014.01)*
H02K 15/04 *(1968.09)*

(52) Cooperative Patent Classification (CPC):
B23K 26/21; B23K 26/32; H02K 15/04

(86) International application number:
PCT/JP2021/011791

(87) International publication number:
WO 2021/220666 (04.11.2021 Gazette 2021/44)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **30.04.2020 JP 2020079962**

(71) Applicants:
- **Daikin Industries, Ltd.**
  Osaka-shi, Osaka 530-0001 (JP)
- **OSAKA UNIVERSITY**
  Suita-shi
  Osaka 565-0871 (JP)

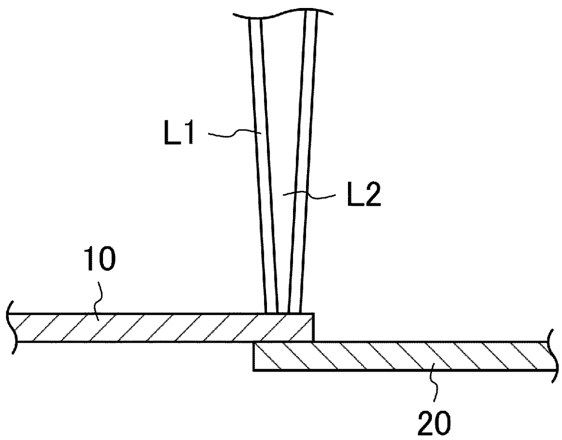
(72) Inventors:
- **ITOU, Masatoshi**
  Osaka-shi, Osaka 530-8323 (JP)
- **NISHIKAWA, Takashi**
  Osaka-shi, Osaka 530-8323 (JP)
- **TSUKAMOTO, Masahiro**
  Suita-shi, Osaka 565-0871 (JP)
- **SATO, Yuji**
  Suita-shi, Osaka 565-0871 (JP)
- **SUGA, Tetsuo**
  Suita-shi, Osaka 565-0871 (JP)

(74) Representative: **Goddar, Heinz J.**
Boehmert & Boehmert
Anwaltspartnerschaft mbB
Pettenkoferstrasse 22
80336 München (DE)

(54) LASER WELDING METHOD AND METHOD FOR MANUFACTURING ELECTRIC ROTATING MACHINE USING SAME

(57) In a laser welding method, a material (10) containing copper as a main component is heated by irradiation with a first laser light (L 1), and is welded by irradiation of a portion, which has been irradiated with the first laser light (L1), of the material (10) with a second laser light (L2) with which the energy absorption rate of copper contained in the material (10) increases by an increase in the temperature of the material (10).

FIG.1



EP 4 129 558 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a laser welding method and a method for manufacturing an electric rotating machine by the laser welding method.

BACKGROUND ART

[0002] A welding method using laser light has been widely known. For example, Patent Document 1 discloses that a workpiece is preheated by irradiation with a first laser light along a planned welding line, and is welded by irradiation of the preheated portion with a second laser light while a filler wire is supplied to the preheated portion.

CITATION LIST

PATENT DOCUMENT

[0003] Patent Document 1: Japanese Unexamined Patent Publication No. 2009-269036

SUMMARY OF THE INVENTION

SOLUTION TO THE PROBLEM

[0004] In an electric rotating machine such as an electric motor or an electric generator, a plurality of conductor segments is respectively inserted into a plurality of slots formed at a stator core, and end portions of the conductor segments inserted into the slots are welded.

[0005] In the case where the end portions of the conductor segments are welded by arc welding, it is, due to high heat input, necessary to increase the length of an exposed conductor portion extending to the end portion of the conductor segment in order to prevent melting of an insulating coating that insulates among the conductor segments, and for this reason, it is difficult to reduce a coil end portion in size. Moreover, for arc welding, grounding is necessary.

[0006] In the case of using laser light, welding can be performed with less thermal influence because of high energy density. However, the conductor segment is generally made of copper, and copper has a low energy absorption rate in the wavelength range of the laser light used for welding. For this reason, it is difficult to perform welding with the laser light.

[0007] It is an object of the present disclosure to provide a laser welding method for welding a material containing copper as a main component with laser light.

SOLUTION TO THE PROBLEM

[0008] A first aspect of the present disclosure is directed to a laser welding method for welding a material (10) containing copper as a main component. The method includes heating the material (10) by irradiation with a first laser light (L1) and welding the material (10) by irradiation of a portion, which has been irradiated with the first laser light (L1), of the material (10) with a second laser light (L2) with which an energy absorption rate of copper contained in the material (10) increases by an increase in a temperature of the material (10).

[0009] In the first aspect, the material (10) containing copper as the main component is heated by irradiation with the first laser light (L1). In addition, the portion of the material (10) irradiated with the first laser light (L1) is irradiated with the second laser light (L2). With the second laser light (L2), the energy absorption rate of copper contained in the material (10) increases by an increase in the temperature of the material (10). Thus, when the portion heated and temperature-increased by irradiation with the first laser light (L1) is irradiated with the second laser light (L2), the second laser light (L2) is absorbed by copper contained in the material (10) at a high energy absorption rate, and high energy density is applied to the material (10). Accordingly, the material (10) is melted, and can be welded. Thus, the material (10) containing copper as the main component can be welded using a combination of the first and second laser lights (L1, L2).

[0010] A second aspect of the present disclosure is an embodiment of the first aspect. In the second aspect, the wavelength of the first laser light (L1) is 584 nm or less. In the second aspect, the temperature of the material (10) can be efficiently increased.

[0011] A third aspect of the present disclosure is an embodiment of the second aspect. In the third aspect, the wavelength of the first laser light (L1) is 470 nm or less. In the third aspect, since the energy absorption rate of copper is increased, the temperature of the material (10) can be stably increased.

[0012] A fourth aspect of the present disclosure is an embodiment of any one of the first to third aspects. In the fourth aspect, a light source of the first laser light (L1) is a diode laser. In the fourth aspect, the first laser light (L1) can be easily obtained.

[0013] A fifth aspect of the present disclosure is an embodiment of any one of the first to fourth aspects. In the fifth aspect, the wavelength of the second laser light (L2) is 800 nm or more. In the fifth aspect, the material (10) can be efficiently brought into a weldable molten state.

[0014] A sixth aspect of the present disclosure is an embodiment of any one of the first to fifth aspects. In the sixth aspect, a light source of the second laser light (L2) is an infrared laser. In the sixth aspect, the second laser light (L2) can be easily obtained.

[0015] A seventh aspect of the present disclosure is an embodiment of any one of the first to sixth aspects. In the seventh aspect, the number of beams of the second laser light (L2) is one or more for one beam of the first laser light (L1). In the seventh aspect, the number of beams of the second laser light (L2) is at least one for one beam of the first laser light (L1), but if there are two or more beams of the second laser light (L2) for one beam of the first laser light (L1), the material (10) can be more uniformly melted.

[0016] An eighth aspect of the present disclosure is an embodiment of any one of the first to seventh aspects. In the eighth aspect, the material (10) is irradiated with two or more pairs of the first and second laser lights (L1, L2). In the eighth aspect, variation in welding can be reduced.

[0017] A ninth aspect of the present disclosure is directed to a method for manufacturing an electric rotating machine (30) in which a plurality of conductor segments (32) is respectively inserted into a plurality of slots formed at a stator core (31) and end portions of the plurality of conductor segments (32) inserted into the slots are made of a material (10) containing copper as a main component. The method includes welding the end portions of the plurality of conductor segments (32) by the laser welding method of any one of the first to ninth aspects.

[0018] In the ninth aspect, the first and second laser lights (L1, L2) are combined so that the end portions of the conductor segments (32) made of the material (10) containing copper as the main component can be welded to each other. Since high energy density is applied to the conductor segment (32), it is not necessary to increase the length of an exposed conductor portion extending to the end portion of the conductor segment (32), and therefore, a coil end portion can be reduced in size. Further, since high-speed welding among the end portions of the conductor segments (32) can be performed, a high production capacity can be obtained. Moreover, since additional equipment for obtaining a high production capacity is not necessary, reduction in an equipment investment can be achieved.

[0019] A tenth aspect of the present disclosure is an embodiment of the ninth aspect. In the tenth aspect, each of the end portions of the plurality of conductor segments (32) is irradiated with one or more pairs of the first and second laser lights (L1, L2). In the tenth aspect, variation in welding among the end portions of the conductor segments (32) can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

FIG. 1 is a sectional view showing a laser welding method according to an embodiment.

FIG. 2 is a graph showing a relationship between the wavelength of laser light at 300 K and the energy absorption rates of various metals including copper.

FIG. 3 is a plan view showing the positions of beams of first and second laser lights (L1, L2).

FIG. 4 is a plan view showing a variation of the positions of beams of the first and second laser lights (L1, L2).

FIG. 5 is a perspective view of an electric rotating machine (30).

FIG. 6 is a perspective view showing a laser welding method for laser-welding end portions of a plurality of conductor segments (32) of the electric rotating machine (30).

FIG. 7 is a perspective view showing the welded end portions of the plurality of conductor segments (32) of the electric rotating machine (30).

FIG. 8 is a perspective view showing a variation of the laser welding method for laser-welding the end portions of the plurality of conductor segments (32) of the electric rotating machine (30).

FIG. 9 is a front view of the welded end portions of the conductor segments (32).

FIG. 10 is a perspective view showing a method for irradiating the end portions of the conductor segments (32) with the first and second laser lights (L1, L2).

FIG. 11 is a perspective view showing a variation of the method for irradiating the end portions of the conductor segments (32) with the first and second laser lights (L1, L2).

DESCRIPTION OF EMBODIMENTS

[0021] In the following, an embodiment will be described in detail.

[0022] In a laser welding method according to the embodiment, a material (10) containing copper as a main component is irradiated with laser light, and is welded to a bonding target metal material (20). In this case, as shown in FIG. 1, a surface of the material (10) is heated by irradiation with a first laser light (L1), and is welded to the bonding target metal material (20) by irradiation of the heated surface of the portion, which has been irradiated with the first laser light (L1), of the material (10) with a second laser light (L2) with which the energy absorption rate of copper contained in the material (10) increases by an increase in the temperature of the material (10).

[0023] In the laser welding method according to this embodiment, the material (10) containing copper as the main component is heated by irradiation with the first laser light (L 1). In addition, the portion of the material (10) irradiated with the first laser light (L1) is irradiated with the second laser light (L2). With the second laser light (L2), the energy absorption rate of copper contained in the material (10) increases by an increase in the temperature of the material (10). Thus, when the portion heated and temperature-increased by irradiation with the first laser light (L1) is irradiated with the second laser light (L2), the second laser light (L2) is absorbed by copper contained in the material (10) at a high energy absorption rate, and the high energy density is applied to the material (10). Accordingly, the material (10) is melted, and can be welded to the bonding target metal material (20). Thus, the material (10) containing copper as the main component can be welded to the bonding target metal material (20) by use of a combination of the first and second laser lights (L1, L2).

[0024] For example, as shown in FIG. 2, for a laser light having a wavelength band of around 500 nm, the energy absorption rate of copper is high, but it is difficult to obtain a level of high energy density which can be used for welding. On the other hand, a laser light having a wavelength band of around 1000 nm can provide high energy density suitable for welding, but the energy absorption rate of copper is low for such a laser light. Here, copper has such properties that when the temperature increases, the energy absorption rate for the laser light having a wavelength band of around 1000 nm increases. Accordingly, the former can be suitably used as the first laser light (L1), and the latter can be suitably used as the second laser light (L2).

[0025] Here, the material (10) containing copper as the main component may be either pure copper or a copper alloy containing 50 mass% or more of copper. The bonding target metal material (20) may be made of the same metal as in the material (10), which contains copper as a main component, or may be made of a different type of metal.

[0026] The wavelength of the first laser light (L1) is preferably 584 nm or less for efficiently increasing the temperature of the material (10), and is more preferably 470 nm, at which the energy absorption rate of copper is high, for stably increasing the temperature of the material (10). The wavelength of the first laser light (L1) is preferably 400 nm or more for a practical perspective. The first laser light (L1) may be a single-wavelength laser light, or may be laser light with a plurality of different wavelengths superimposed.

[0027] The energy absorption rate of copper contained in the material (10) for the first laser light (L1) at 300 K is preferably 60% or more, more preferably 80% or more for efficiently increasing the temperature of the material (10).

[0028] The power density of the first laser light (L1) is preferably 125000 W/cm^2 or more, more preferably 500000 W/cm^2 or more, and preferably 5100000 W/cm^2 or less for efficiently increasing the temperature of the material (10).

[0029] A light source of the first laser light (L1) is preferably a diode laser, more preferably one having an oscillation wavelength band of 400 nm or more to 470 nm or less as described above.

[0030] The temperature of the material (10) heated by irradiation with the first laser light (L1) is preferably 200°C or more, more preferably 400°C or more, and preferably 1083°C or less for increasing the energy absorption rate for the second laser light (L2).

[0031] The wavelength of the second laser light (L2) is preferably 800 nm or more, more preferably 1030 nm or more, and preferably 1500 nm or less for efficiently bringing the material (10) into a weldable molten state. The wavelength of the second laser light (L2) is preferably 1200 nm or less for a practical perspective The second laser light (L2) may be a single-wavelength laser light, or may be laser light with a plurality of different wavelengths superimposed.

[0032] The energy absorption rate of copper contained in the material (10) for the second laser light (L2) after the temperature has increased is preferably 30% or more, more preferably 60% or more for bringing the heated material (10) into the weldable molten state. The energy absorption rate of copper contained in the material (10) for the second laser light (L2) at 300 K before the temperature increases is, for example, 0.9% or more to 8.0% or less.

[0033] The power density of the second laser light (L2) is preferably 6250000 W/cm^2 or more, more preferably 20000000 W/cm^2 or more, and preferably 200000000 W/cm^2 or less for efficiently bringing the material (10) into the weldable molten state.

[0034] A light source of the second laser light (L2) is preferably an infrared laser.

[0035] Irradiation of the material (10) with the first and second laser lights (L1, L2) is preferably performed such that the second laser light (L2) is contained in the first laser light (L1), as shown in FIGS. 3 to 5. The number of beams of the second laser light (L2) is one or more for one first laser light (L1), and as shown in FIG. 3, is at least one for one first laser light (L1). However, if there are two or more beams of the second laser light (L2) for one beam of the first laser light (L1) as shown in FIG. 4, the material (10) can be more uniformly melted.

[0036] Next, a method of manufacturing an electric rotating machine (30) such as an electric motor or an electric generator by the laser welding method according to the embodiment will be described.

[0037] As shown in FIG. 5, in the electric rotating machine (30), a plurality of conductor segments (32) is respectively inserted into a plurality of slots (not shown) formed at a stator core (31), and end portions of the plurality of conductor segments (32) inserted into the slots are made of the material (10) containing copper as the main component. Then, in such manufacturing, each of the end portions of the plurality of conductor segments (32) is spot-irradiated with the first and second laser lights (L1, L2) by the laser welding method according to the embodiment, as shown in FIG. 6. Accordingly, the end portions of the plurality of conductor segments (32) are welded to each other as shown in FIG. 7. In this case, the end portions of the plurality of conductor segments (32) may be irradiated with the first and second laser lights (L1, L2) such that the first and second laser lights (L1, L2) are swept thereon, as shown in FIG. 8.

[0038] As described above, the first and second laser lights (L1, L2) are combined using the laser welding method according to the embodiment so that the end portions of the conductor segments (32) made of the material (10) containing copper as the main component can be welded to each other. In this case, since the first laser light (L1) having a low energy density and the second laser light (L2) having a high energy density are superimposed on each other, a thermally-conductive welding portion (33) welded so as to be bridged between end surfaces of the conductor segments (32) and a keyhole-shaped welding portion (34) welded by Infiltration of the material (10) into between the end portions of the conductor segments (32) are formed between the end portions of the conductor segments (32) as shown in FIG. 9. Thus, a high welding strength can be obtained.

[0039] Since high energy density is applied to the conductor segment (32), it is not necessary to increase the length of an exposed conductor portion extending to the end portion of the conductor segment (32), and therefore, a coil end portion can be reduced in size. Further, since high-speed welding among the end portions of the conductor segments (32) can be performed, a high production capacity can be obtained. Moreover, since additional equipment for obtaining a high production capacity is not necessary, reduction in an equipment investment can be achieved.

[0040] In manufacturing of the electric rotating machine (30), each of the end portions of the plurality of conductor segments (32) is irradiated with one or more pairs of first and second laser lights (L1, L2). Each of the end portions of the plurality of conductor segments (32) is irradiated with at least one pair of first and second laser lights (L1, L2), as shown in FIG. 10. When each end portion is irradiated with two or more pairs of first and second laser lights (L1, L2) as shown in FIG. 11, variation in welding among the end portions of the conductor segments (32) can be reduced.

INDUSTRIAL APPLICABILITY

[0041] The present invention is useful for a laser welding method and a technical field using the laser welding method.

DESCRIPTION OF REFERENCE CHARACTERS

[0042]

L1	First Laser Light
L2	Second Laser Light
10	Material
30	Electric Rotating Machine
31	Stator Core
32	Conductor Segment

Claims

1. A laser welding method for welding a material (10) containing copper as a main component, the laser welding method comprising:
heating the material (10) by irradiation with a first laser light (L1) and welding the material (10) by irradiation of a portion, which has been irradiated with the first laser light (L1), of the material (10) with a second laser light (L2) with which an energy absorption rate of the copper contained in the material (10) increases by an increase in a temperature of the material (10).

2. The laser welding method of claim 1, wherein
a wavelength of the first laser light (L1) is 584 nm or less.

3. The laser welding method of claim 2, wherein
the wavelength of the first laser light (L1) is 470 nm or less.

4. The laser welding method of any one of claims 1 to 3, wherein
a light source of the first laser light (L1) is a diode laser.

5. The laser welding method of any one of claims 1 to 4, wherein
a wavelength of the second laser light (L2) is 800 nm or more.

6. The laser welding method of any one of claims 1 to 5, wherein
a light source of the second laser light (L2) is an infrared laser.

7. The laser welding method of any one of claims 1 to 6, wherein
the number of beams of the second laser light (L2) is one or more for one beam of the first laser light (L1).

8. The laser welding method of any one of claims 1 to 7, wherein
the material (10) is irradiated with two or more pairs of first and second laser lights (L1, L2).

9. A method for manufacturing an electric rotating machine (30) in which a plurality of conductor segments (32) is respectively inserted into a plurality of slots formed at a stator core (31) and end portions of the plurality of conductor segments (32) inserted into the slots are made of a material (10) containing copper as a main component, the method comprising:
welding the end portions of the plurality of conductor segments (32) by the laser welding method of any one of claims 1 to 8.

10. The method of claim 9, wherein
each of the end portions of the plurality of conductor segments (32) is irradiated with one or more pairs of first and second laser lights (L1, L2).

FIG.1

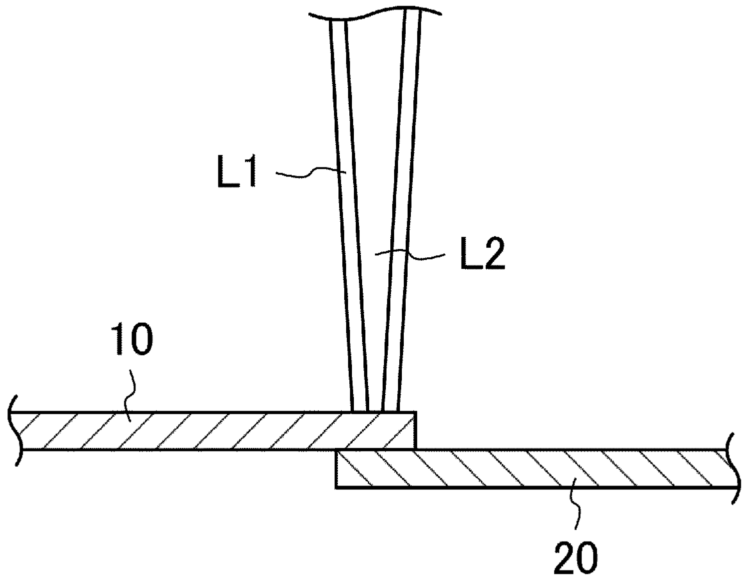


FIG.2

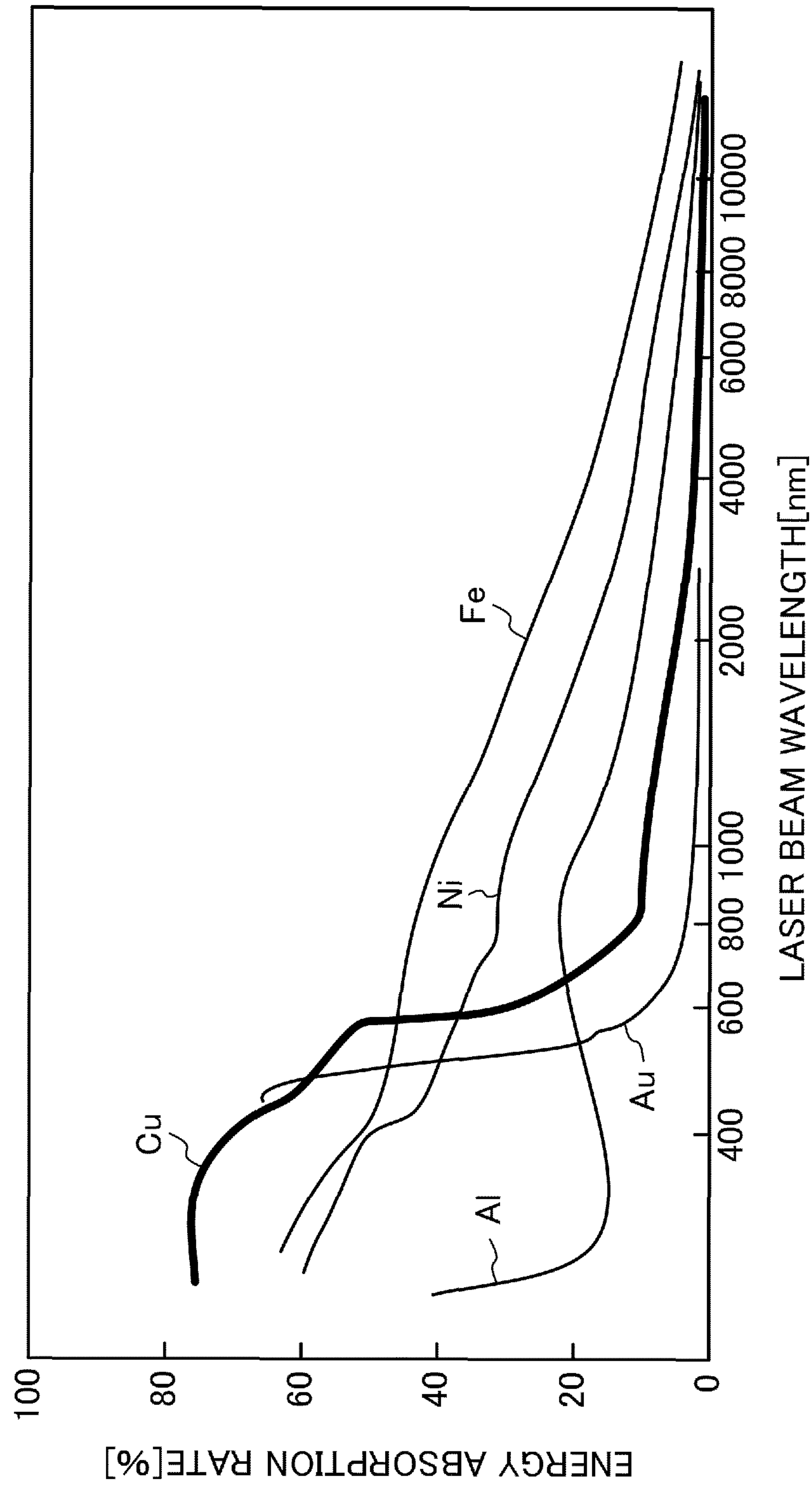

ENERGY ABSORPTION RATE[%]
100
80
60
40
20
0
LASER BEAM WAVELENGTH[nm]
400
600
800
1000
2000
4000
6000
8000
10000
Cu
Al
Ni
Au
Fe

FIG.3

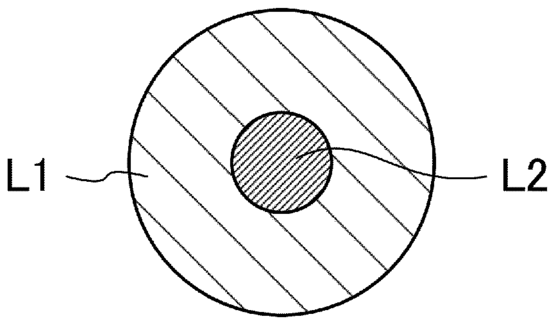


FIG.4

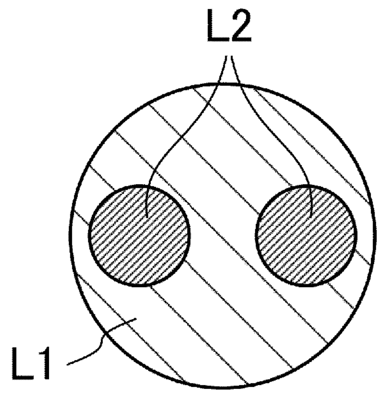


FIG.5

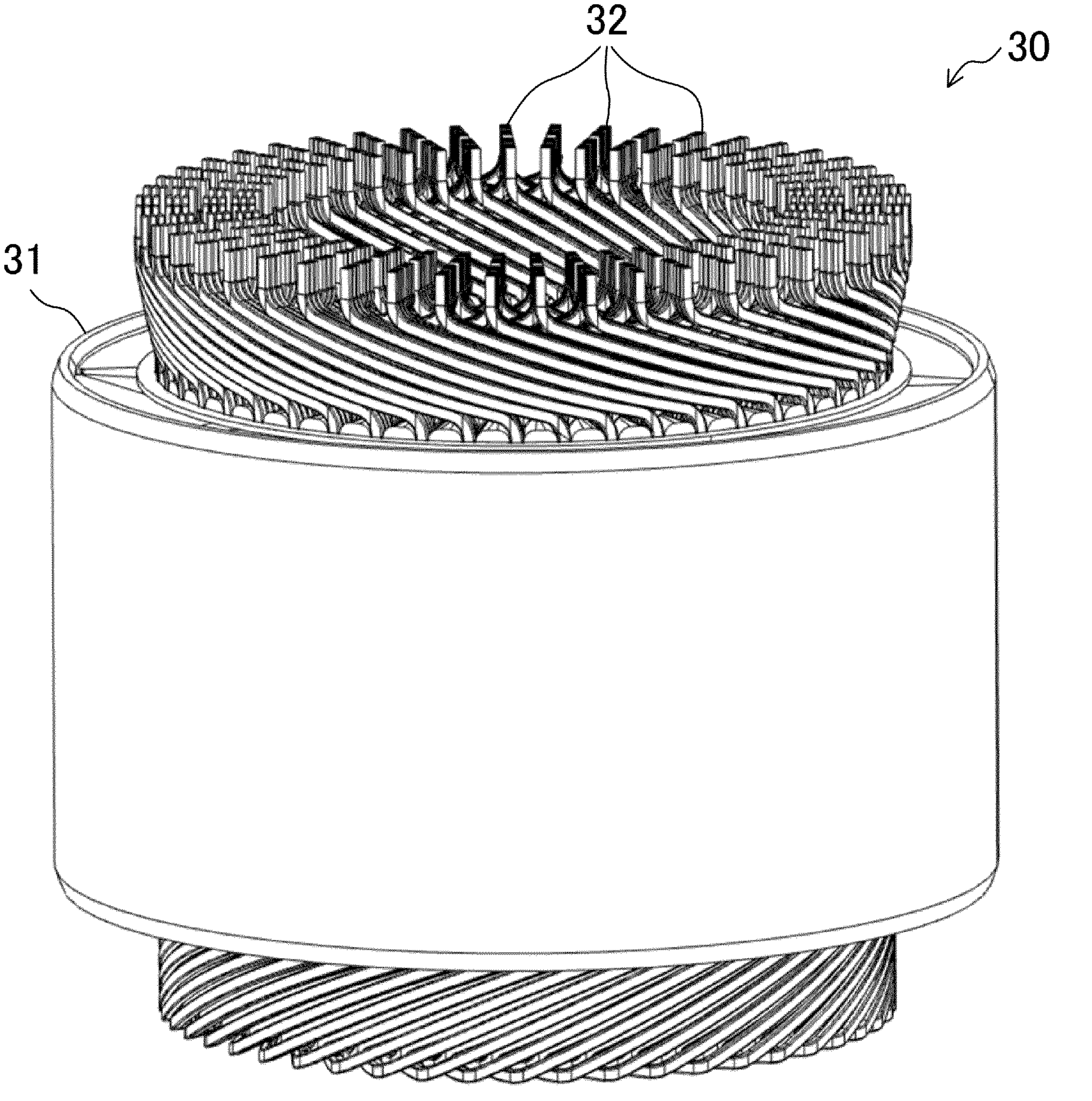


FIG.6

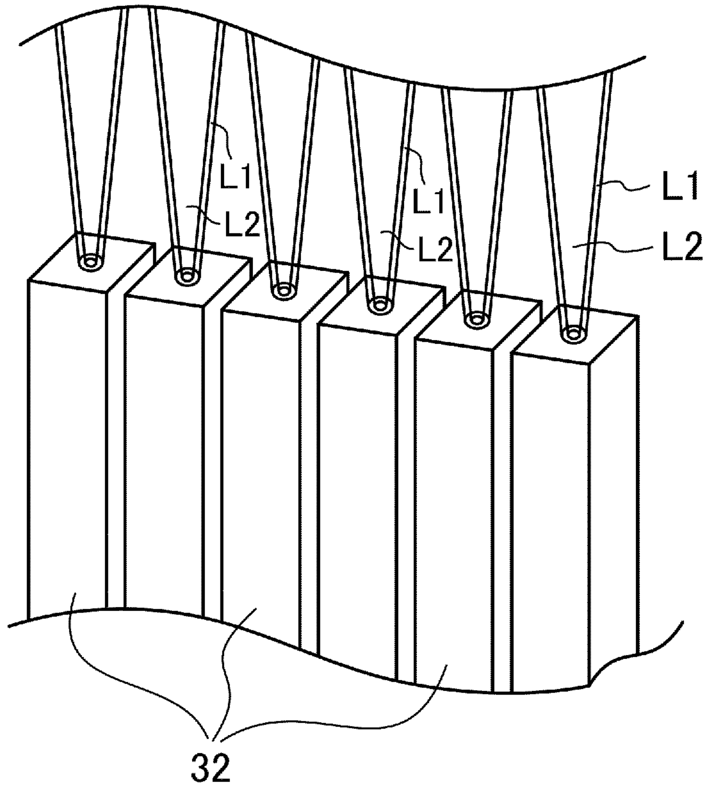


FIG.7

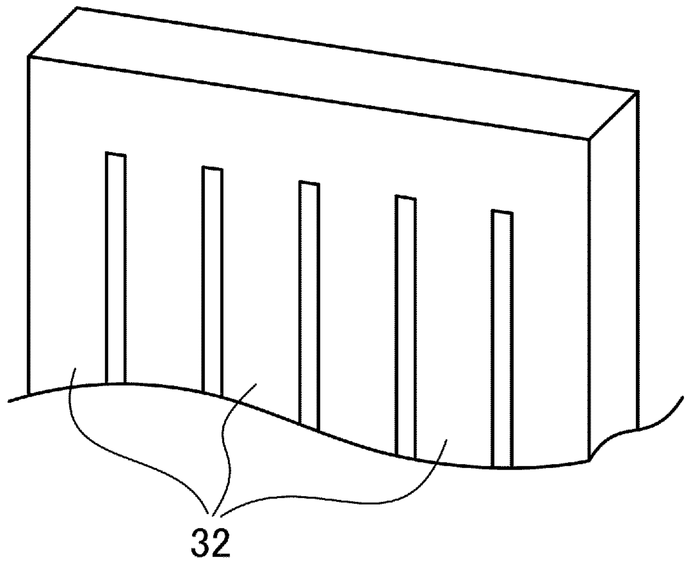


FIG.8

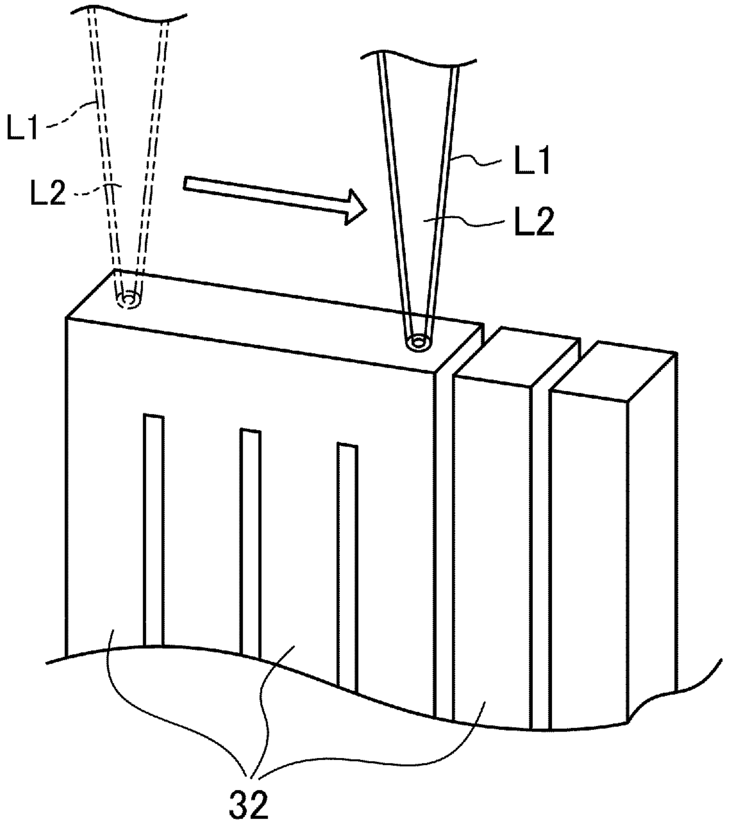


FIG.9

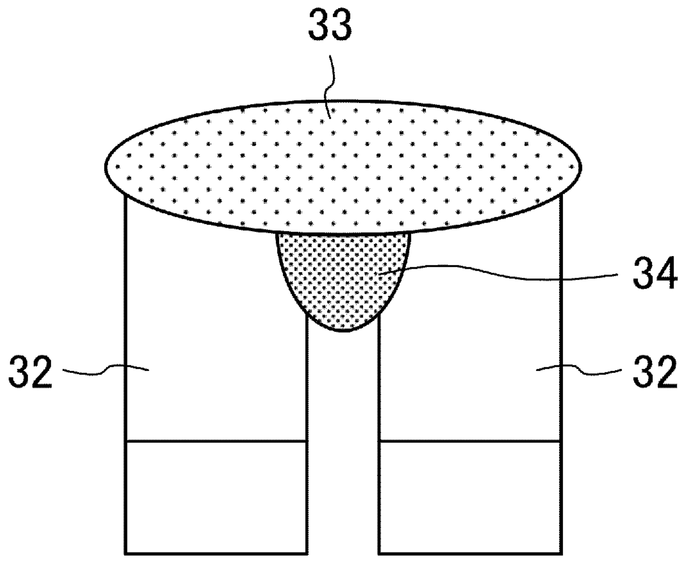


FIG.10

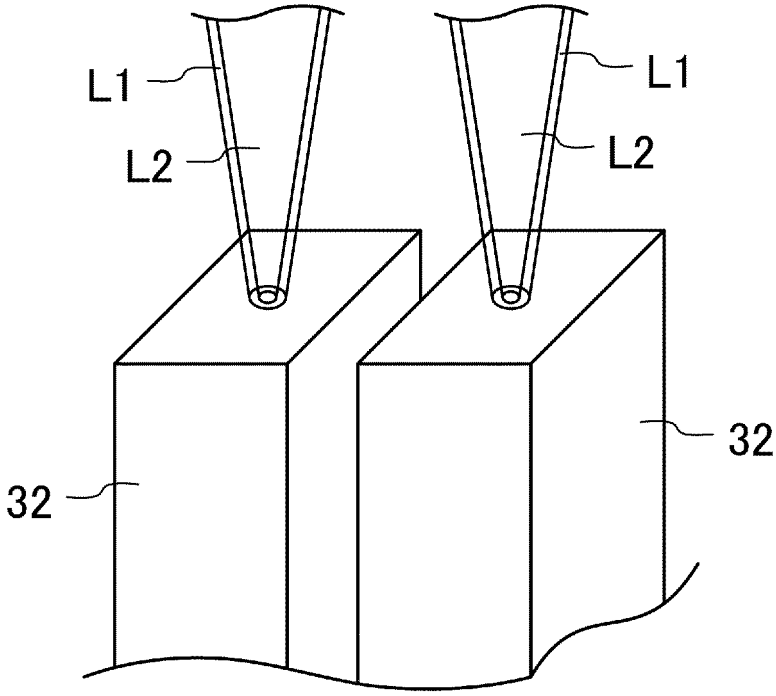
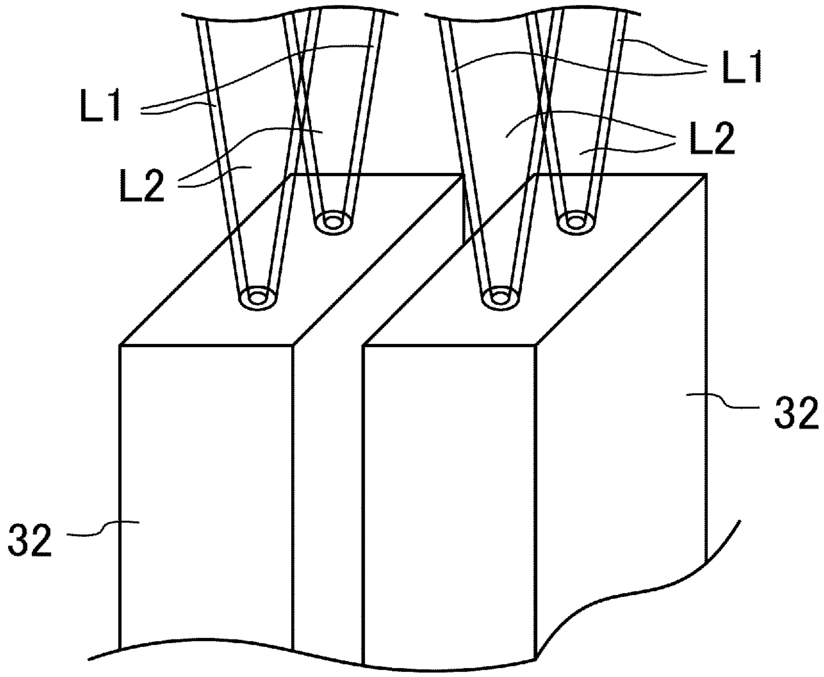


FIG.11



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/011791

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. B23K26/32(2014.01)i, B23K26/21(2014.01)i, H02K15/04(2006.01)i
FI: B23K26/32, B23K26/21N, H02K15/04E

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. B23K26/32, B23K26/21, H02K15/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 05-104276 A (TOSHIBA CORPORATION) 27 April 1993 (1993-04-27), paragraphs [0014]-[0019], [0035], [0036], fig. 1	1-7 8-10
X Y A	JP 2005-313195 A (MIYACHI TECHNOS CORP.) 10 November 2005 (2005-11-10), paragraphs [0035], [0053]-[0058], fig. 5	1-3, 5-7 8-10 4
Y	JP 2020-039191 A (MITSUBISHI ELECTRIC CORPORATION) 12 March 2020 (2020-03-12), paragraphs [0031], [0032], [0041]-[0050], fig. 19	8-10
Y	JP 2019-118159 A (TOYOTA MOTOR CORPORATION) 18 July 2019 (2019-07-18), paragraphs [0015], [0016], fig. 4, 5	8-10
Y	JP 2017-098161 A (TOYOTA MOTOR CORPORATION) 01 June 2017 (2017-06-01), paragraphs [0025]-[0028], fig. 9	8-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 April 2021	18 May 2021
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/011791

JP 05-104276 A	27 April 1993	(Family: none)
JP 2005-313195 A	10 November 2005	(Family: none)
JP 2020-039191 A	12 March 2020	(Family: none)
JP 2019-118159 A	18 July 2019	(Family: none)
JP 2017-098161 A	01 June 2017	(Family: none)

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2009269036 A **[0003]**